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Icing Sensor Probe

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March 2002

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ABSTRACT

Aircraft icing is a serious safety problem for the general aviation and some commuter transport airplanes. There has been tremendous growth in the commuter aviation industry in the last few years, since these type of aircraft generally operate at lower altitudes they consequently spend a far greater proportion of their time operating in icing conditions.

For the past thirty years airborne and ground based facilities have relied primarily on two types of cloud physics instrumentation to measure the characteristics of icing clouds: hot wire liquid water content probes and laser based particle sizing probes for the measurement of water droplet size. The instrumentation is severely limited by the technology that was developed during the 1970's and is quite large in size. The goal of this research is to develop one instrument with a wide bandwidth, better response time, higher resolution, user selectability, and small and lightweight. NASA Glenn Research Center, Droplet Measurement Technology, and Meteorology Society of Canada have developed a collaborative effort to develop such an instrument. This paper describes the development and test results of the prototype Icing Sensor Probe.

INTRODUCTION

Aircraft icing is a serious safety problem for the general aviation and some commuter transport airplanes. There has been tremendous growth in the commuter aviation industry in the last few years, since these type of aircraft generally operate at lower altitudes they consequently spend a far greater proportion of their time operating in icing conditions.

In the past several years there have been a number of fatal commuter aircraft accidents attributed to a severe icing conditions having Supercooled Large Droplets (SLD). Though SLD was thought to occur infrequently, the significant increase in commuter aircraft traffic has raised a concern that the chances of encountering this icing

conditions may be far greater than previously thought. At the present time aircraft ice protection systems are not required to provide protection against SLD.

Given NASA's current Aviation Safety Program initiative to significantly reduce aircraft accidents, it is important that the frequency of occurrence be established. Once this frequency of occurrence is established, the FAA can use this information to affect changes in current aircraft icing certification regulations. This in turn would enable the FAA to require changes in the design of aircraft ice protection systems, potentially to protect against SLD.

Present research activities aimed at establishing this frequency of occurrence have been limited to a handful of research organizations using heavily instrumented research aircraft (e.g., NASA's Twin Otter). Though effective, this approach is limited in scope and somewhat biased because meteorologists are directing research flights into areas having highest probability of SLD occurrence. Therefore, what is needed is a more extensive random approach, such as that offered by instrumenting large numbers of commercial/military aircraft. The key to this approach is the development of an integrated Icing Instrumentation package, which does not currently exist.

For the past thirty years airborne and ground based facilities have relied primarily on two types of cloud physics instrumentation to measure the characteristics of icing clouds: hot wire liquid water content probes and laser based particle sizing probes for the measurement of water droplet size. The Forward Scattering Spectrometer Probe (FSSP) is limited by slow electronic response times, saturation when in modest concentrations of cloud particles, and lack of resolution in size determination. The Optical Array Probe 2D requires an external controller that sets the data accumulation rate dependent upon the airspeed of the aircraft. Both these instruments use gas lasers that are large, require a high voltage power supply and thirty-year-old electronic technology that is inefficient with respect to weight and power. The hot wire Liquid Water Content probes are a first principle's type device but sensing elements often have a short lifetime due to the fragility of the sensor design and the instability of the control electronics. The instrumentation is severely limited by the technology that was developed during the 1970's and is quite large is size. The goal of this research is to develop one instrument with a wide bandwidth, better response time, higher resolution, user selectability, and small and lightweight. NASA Glenn Research Center, Droplet Measurement Technology, and Meteorology Society of Canada have developed a collaborative effort to develop such an instrument. This paper describes the development and test results of the prototype Icing Sensor Probe.

System Overview

The icing sensing probe (ISP) prototype that has been developed incorporates a forward scattering spectrometer and a 2-D optical array particle imaging probe into a single streamline strut housing. The aerodynamic strut measures 3.5 inches wide and 18.25 inches long with a common sample volume for the two optical measuring systems.

The optical paths are arranged in a fore/aft configuration insuring that the same volume of the cloud is measured by each optical probe. The sample flow channel is 1.5 inches wide by 4.5 inches high and has small faring on the top and bottom to prevent splattering of cloud water on the windows for the optical measurement probes. The leading edge of the strut, the flows channel, and the wetless windows are heated to minimize the buildup of ice under supercooled cloud liquid water conditions. The forward scattering and 2D optical array probes use high power diode lasers, which eliminates the frequently occurring optical noise associated with gas lasers. The particle sizing range of the ISP is from 2 – 1550 μm in size which will meets the needs of aircraft icing studies. The base of the unit houses the electronics for the optical probes. The high-speed digital electronics used to acquire and process the particle information virtually eliminates saturation and response time problems associated with the older particle measuring instruments. The electronics also offer processing options that improve the information content that can be extracted from the measurements. Figure 1 is the engineering drawing on the icing sensor probe (ISP).

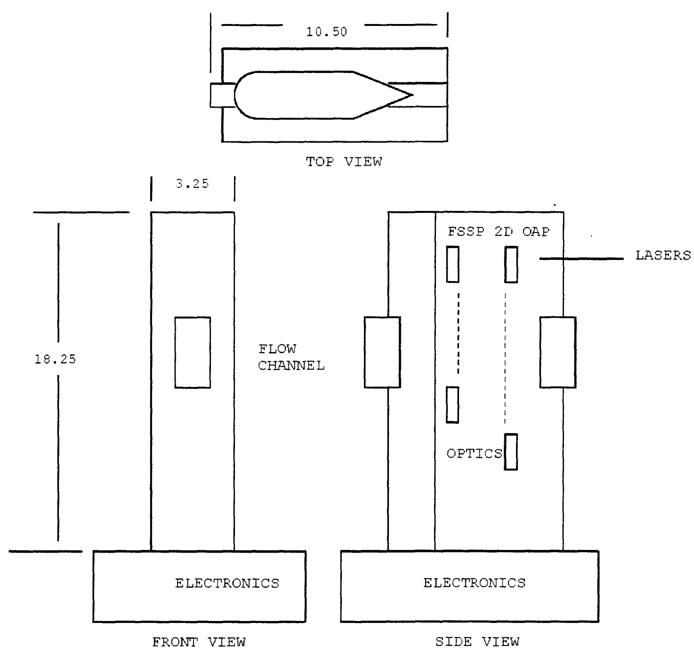

Figure 1

Figure 2 shows a detailed schematic view of the flow path and the optical system. The linear design of the optical path is much more efficient in the use of space. The sampling areas are inline, directly behind each other, so there is no bias in the sampling due to inhomogeneity of the measured cloud. The cloud spectrometer has a very small sample volume, allowing particle concentrations as high as 10,000 particles/cm^3 to be measured without significant interference. The forward scattering probe portion of the instrument has a size range from 2 μm – 50 μm, number concentration range from

0 – 10,000 cm^3, and selectable bin sizes ranging from 10 –40. The optical array probe portion of the instrument has a size range from 25 μm – 1.55 mm, number concentration range from 0 – 100 cm^3, and resolution 25 μm. Table 1 details the specifications for each of the optical measurement portion of the icing sensor probe (ISP).

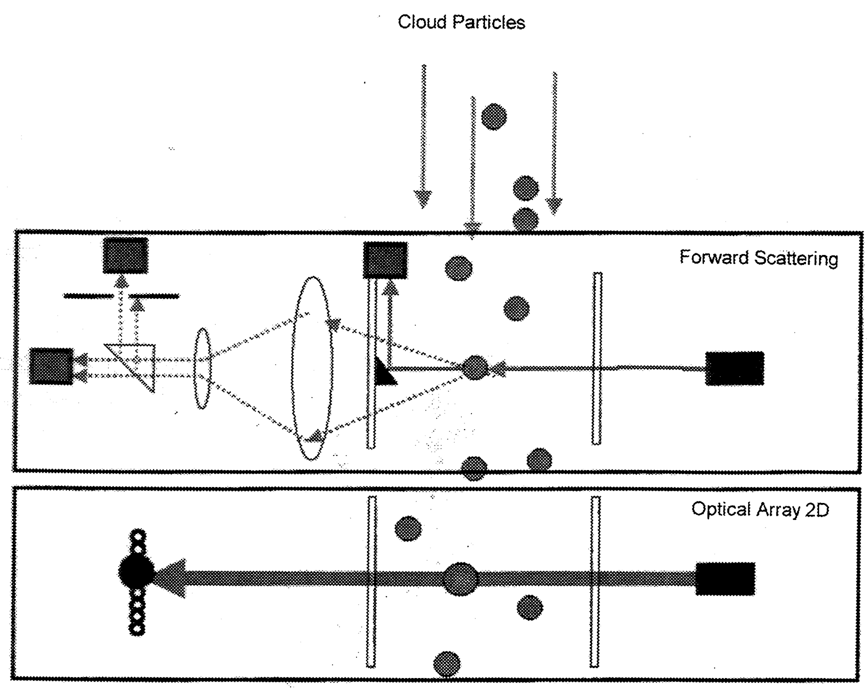

Figure 2

TABLE 1.—INSTRUMENT CHARACTERISTICS

Forward Scattering Probe	
Size Range	2 μm – 50 μm
Sample Area	1.1 mm x 120 μm
Number Conc. Range	0 – 10,000 cm^{-3}
Air Speed Range	10 – 200 ms^{-1}
Number of Size Bins	Selectable, 10 – 40
Sample Frequency	Selectable, 0.1 – 10 Hz
Refractive Index	non-absorbing, 1.30 – 1.70
Light Collection Angles	4 – 12 degrees
Laser Wavelength	680 nm
Data System Interface:	RS-232 or RS-422 @ 19,200 Baud

TABLE 1.— CONCLUDED.

Optical Array 2D Probe	
Size Range Resolution Sample Area Number Conc. Range Air Speed Range Number of Size Bins Sample Frequency Laser Wavelength Data System Interface	25 μm – 1.55 mm 25 μm 10 cm x 1.55 mm 0 – 100 cm^{-3} 10 – 200 ms^{-1} 62 Asynchronous 680 nm RS-232 or RS-422 @ 19,200 Baud
Physical Characteristics	
Size Weight Power Requirements	3.5 inches wide by 18.5 inches long 17 pounds 28 VDC @ 7A for electronics 28VDC @ 23A for anti-icing

Test Results

The Icing Sensor Probe was tested at the National Research Council (NRC) of Canada Altitude Icing Tunnel in Ottawa, May 17, 2000. The tunnel has a cross section of approximately 57 cm x 57 cm, and is capable of airspeeds up to 100 ms^{-1}, temperatures from ambient to –30 °C, and LWCs from 0.1 to 2.0 gm^{-1}. The wind tunnel testing phase of this prototype was to focus primarily on the configuration of the instrument at typical aircraft speeds and to measure cloud size distributions. A test matrix was run at 70 ms^{-1}, from 8 μm medial volume diameter (MVD) up to an estimated MVD of 225 μm and an anti-icing testpoint was conducted at 0.5gm^{-3} liquid water content, –15 °C static temperature, and 100 ms^{-1} airspeed. Figure 3 shows the ISP mounted in the wind tunnel following the ice accumulation tests. There is a small accumulation of ice on the leading edge of the flow channel and the upper section of the probe indicating that these areas need more anti-icing. The lower part of the probe, and the wetless windows in the flow channel are completely free from ice.

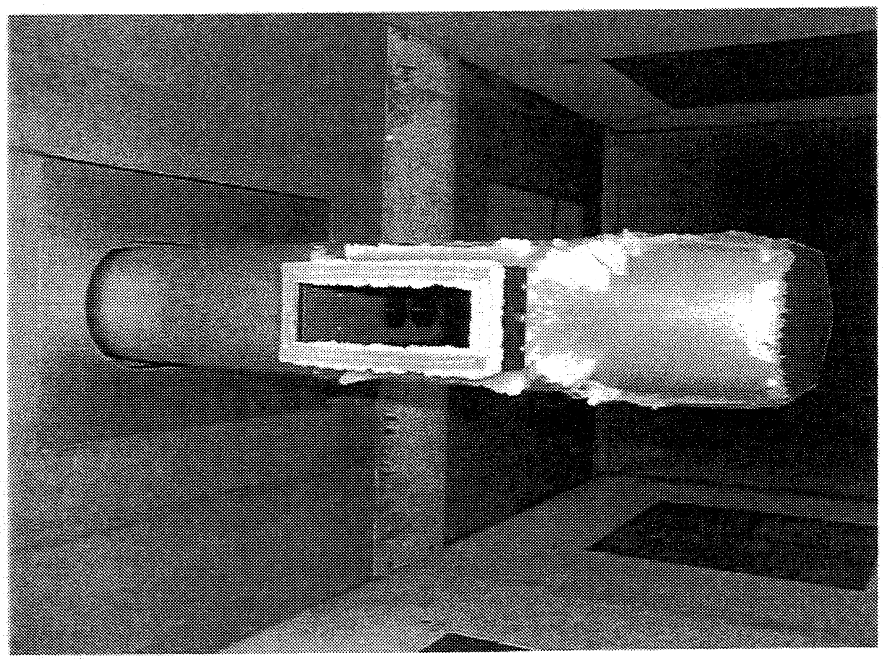

Figure 3

Figure 4 illustrates the size distributions that were measured by the Icing Sensor Probe in the NRC ice tunnel. Two histograms are shown in this figure 5. The histograms drawn with solid lines are for a tunnel condition with LWC 1 gm^{-3} and MVD of 33 μm. The dark dashed lines are measurements taken at LWC 1 gm^{-3} and MVD of 69 μm. The 33 μm MVD case shows good agreement between the forward scattering instrument and the optical array 2D instrument. The 69 μm MVD case shows poor agreement between the two instruments as expected since the concentration of droplets is larger than the maximum size of the forward scattering instrument. The purpose of this test is to demonstrate the broad range of particles that can be acquired by this instrument. From small drop sizes to the critical freezing drizzle spectrum.

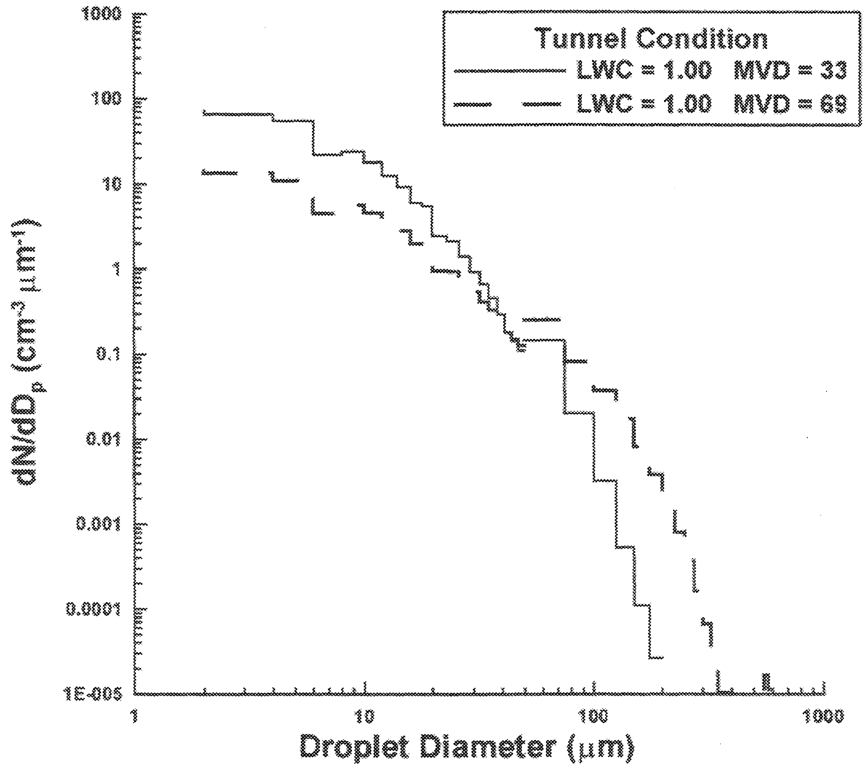

Figure 4

Table 2 is a list of LWC and MVD parameters that were used to test the Icing Sensor Probe in the NRC icing tunnel.

TABLE 2

Tunnel LWC	Forward Scattering LWC	Forward Scattering and Optical Array 2D LWC	Tunnel MVD	Forward Scattering MVD	Forward Scattering and Optical Array 2D MVD
0.82	0.48	0.5	18	17	18.6
0.95	0.54	0.96	32	25.9	44.5
1.04	0.45	1.92	47	29.7	79.3
0.86	0.5	0.6	23	20	28
1	0.46	1.31	39	27.8	60.9

The scatter plots figure 5 compares the measured MVD of the Icing Sensor Probe to the NRC nominal tunnel values and figure 6 compares the LWC of the Icing Sensor Probe to the NRC nominal tunnel values. The comparison of the ISP to the tunnel MVD illustrates that the FSSP underestimates these measurements. The addition of the 2D optical array measurements brings the MVD values closer to the predicted tunnel values. The MVD's for the NRC Icing Tunnel are derived from test made with the Malvern particle measurement instrument. Test conducted in other icing research tunnels from a combination of particle measuring instruments could lead to MVD's discrepancies on the average of 30 percent and in specific size ranges by a factor of two. The MVD estimates from the ISP are provided to demonstrate that the MVDs increase when expected. The LWC measurements are derived from the integration of the size distributions and any error in the size distributions directly affects the LWC calculations. These LWC discrepancies are similar to those found in other icing research tunnels using the best combination of small and large droplets measurements from a combination of particle measuring instruments.

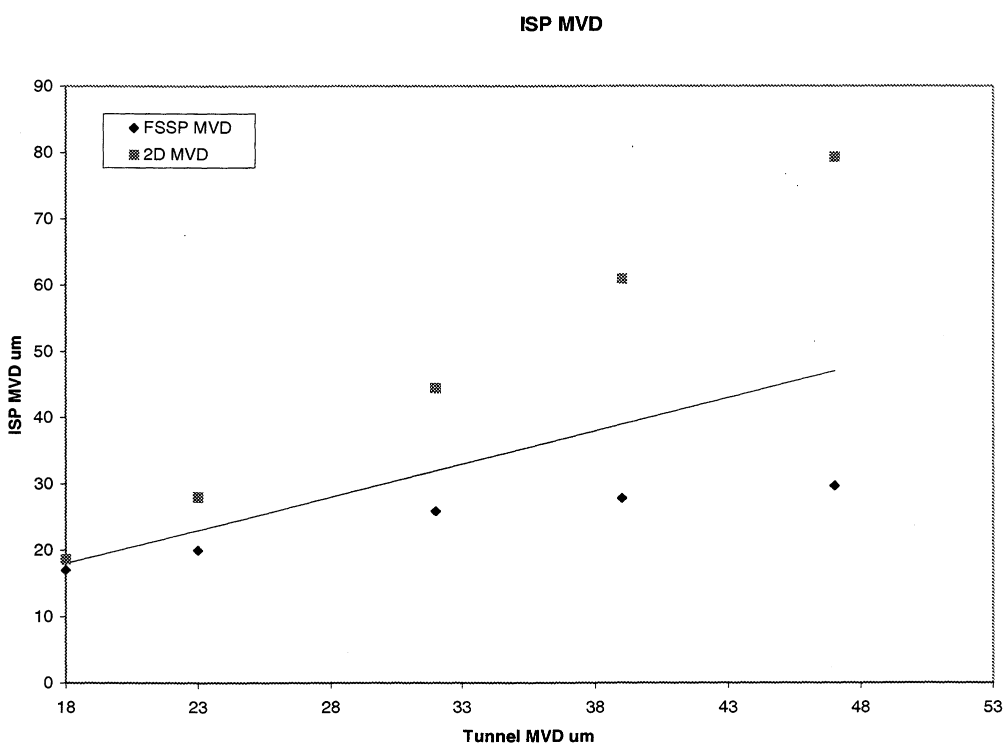

Figure 5

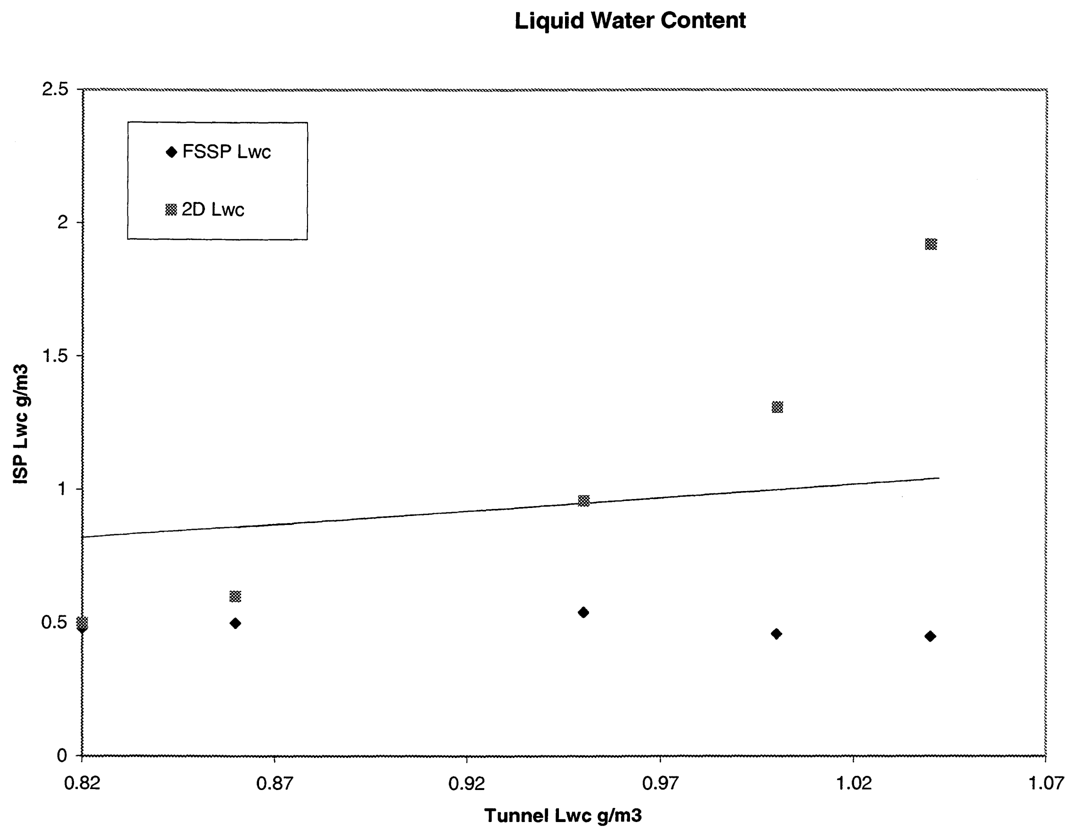

Figure 6

Summary

The primary results of the test in the NRC Icing Tunnel indicate that the ISP shows good sensitivity to drizzle size droplets. The size histograms indicate a reasonable shape consistent with exponential cloud droplet distributions. The changes in the tunnel MVDs were reflected in changes in the measured values form the ISP. Although the ISP MVDs were somewhat larger. The LWC comparisons of the NRC tunnel and the ISP instrument are promising and similar results have been demonstrated in other tunnel instrumentation comparison tests. Small accumulations of ice on the leading edge of the flow channel and upper portion of the probe indicate that additional work needs to be done in anti-icing of the instrument.

Future Development

The current version of the Icing Sensing Probe will be redesigned into the next phase called the Integrated Sensor for Icing Studies. This next generation will incorporate the forward scattering probe, optical array 2D probe, liquid and total water content sensors, ice detector, local airspeed measurement, and outside air temperature

sensor. The physical configuration will be similar to the Icing Sensor Probe with some minor modifications. The sample tube, which is presently rectangular, will be resigned to use a cylindrical sample tube, this will minimize the cloud droplet interception at high angle of attacks. The forward scattering instrumentation's size range will be change to 2 – 90 microns and optical array instrument's range will be changed to 10 – 620 microns, which will provide a more complete spectrum which is important to cloud physics characterization. The clock speed of the optical array 2D will be increased to 10 MHz to keep 10 micron resolution at aircraft speeds up to 100 meters per second, which is important for habit recognition of droplets. Another important feature will be software selectable thresholds, this will prevent the instrument from being overloaded during high concentrations of small particles less than 50 microns. The addition of the liquid water content sensors will not only provide the amount of liquid water content but also the amount of water content in ice particles. This will result in a more accurate estimate of liquid water content in rain and drizzle. The ambient temperature and airspeed will be measured in close proximity to the sample channel of the particle measuring instruments. A Rosemount ice rate sensor will also be incorporated which provides a direct link between icing rates, liquid water content, and particle spectrum.

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Aircraft icing is a serious safety problem for the general aviation and some commuter transport airplanes. There has been tremendous growth in the commuter aviation industry in the last few years, Since these type of aircraft generally operate at lower altitudes they consequently spend a far greater proportion of their time operating in icing conditions. For the past thirty years airborne and ground based facilities have relied primarily on two types of cloud physics instrumentation to measure the characteristics of icing clouds: hot wire liquid water content probes and laser based particle sizing probes for the measurement of water droplet size. The instrumentation is severely limited by the technology that was developed during the 1970's and is quite large in size. The goal of this research is to develop one instrument with a wide bandwidth, better response time, higher resolution, user selectability, and small and lightweight. NASA Glenn Research Center, Droplet Measurement Technology, and Meteorology Society of Canada have developed a collaborative effort to develop such an instrument. This paper describes the development and test results of the prototype Icing Sensor Probe.

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